Crimean orogen: a nappe interpretation

I. V. Popadyuk & S. E. Smirnov

Ukrainian State Geological Research Institute,
Mitskevich sq. 8, 290601 Lviv, Ukraine

ABSTRACT

Detailed surface geological analyses and a review of subsurface and published palaeontological data refute the long held notion that the area of the Crimean Highlands was affected by a major Late Triassic-Early Jurassic orogeny, referred to as the Early Cimmerian orogenic pulse. The Taurian flysch, which contains abundant reworked Carboniferous to Jurassic rock fragments and which was previously thought to be of Late Triassic to Early Jurassic age, has been redated on the basis of Ammonites as Hauterivian to Aptian. Correspondingly, an older-over-younger relationship, typical for nappe tectonics, has been established for the Late Jurassic carbonates, the Taurian flysch and the Albian-Aptian autochthonous series which crop out in the Crimean Highlands.

The topographic relief of the Crimean Highlands is upheld by 800-1000 m thick Late Jurassic reefal and platform carbonates forming the Yayla nappe. In the southern parts of the area this nappe rests on the Taurian nappe and further north on autochthonous series. The Taurian nappe is composed of Hauterivian to Aptian flysch. The Yayla and Taurian nappes each account for horizontal northward transport of supra-crustal rocks over a distance of at least 30-40 km; their root zones, which may be located off-shore, have not yet been identified. The youngest autochthonous strata which are overridden by these nappes yield a middle Late Albian age. The thrust contact between the Taurian nappe and the autochthon is sealed by Cenomanian limestones. Therefore, the main deformation phase of the Crimea, during which the Yayla and Taurian nappes were emplaced, is dated as Late Albian and thus correlates with the Austrian phase of the Alpine orogenic cycle.

In the northeastern part of the Crimea, subsurface data give evidence for Eocene and younger compressional reactivation of the frontal parts of the Yayla nappe, corresponding to the Vladislavovka nappe which involves Late Jurassic to Paleogene strata. The effect of these Late Alpine deformations on the Crimea Highlands is difficult to evaluate for want of a Late Cretaceous and younger stratigraphic record.

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INTRODUCTION

The southern most parts of the Crimean Peninsula are occupied by highlands which are upheld by folded and thrusted, partly reefal Late Jurassic carbonates and Early Cretaceous flysch series. These northeasterly trending highlands, which rise to an elevation of nearly 1500 (highest peak Roman-Kosh Mtn. 1543 m elevation), have a length of some 170 km and are up to 50 km wide. Geophysical data indicate that the Crimean orogen extends off-shore in the direction of the Dobrogea and the Greater Caucasus as well as to the south into the deeper waters of the Black Sea (Khain, 1994).

The Crimean Highlands are one of the best studied parts of the Alpine chains of Eastern Europe. Surface geological mapping had already commenced during the second half of the 19th century. By the late 1960's more than 1300 papers had been published on this area. This voluminous literature was synthesized by M.V. Muratov in volume VIII of the "Geology of the USSR" (1969). In this fundamental work the classical model for the evolution of the Crimean orogen was developed. According to this model the geosynclinal stage of the area terminated with the compressional deformation of the Taurian flysch group during Late Triassic-Early Jurassic times. This Early Cimmerian orogenic pulse was supposedly followed by a prolonged period of tectonic quiescence during which Late Jurassic carbonates were deposited on the eroded Early Cimmerian fold belt. Compressional deformation of the area resumed only during the Neogene.

In this model the Crimean fold belt was regarded as an inverted basin in the foreland of the Alpine chains that lacked the classical nappe tectonics which characterize the true Alpine orogens. Although, with the gradual acceptance of plate tectonic concepts, this interpretation began to be seriously questioned, Muratov and Tseisler (1982) continued to adhere to their model. On the other hand, after the publication of the paper by S.L. Byzova (1980), Khain (1994) visualizes a more complex evolution of the Crimean Highlands, involving Early Cimmerian deformation of the Taurian flysch trough, followed by Late Cimmerian (pre-Tithonian) southward thrusting of the Late Jurassic carbonates and Late Alpine deformation of the eastern parts of the Crimean orogen.

Yu.V. Kazantsev (1982) were the first to revise the classical model of Muratov (1969) in the sense of nappe tectonics, however, without considering a revision of the age of the Taurian flysch complex. Although these early efforts were strongly criticized (Archipov et al., 1983a, 1983b; Byzova et al., 1983), additional impulses were given to the more mobilistic nappe model by the recognition of nappes in the Kerch Peninsula located to the east of the Crimean Highlands (Kazantsev and Beher, 1987; Kruglov and Tsypko, 1988). This discovery encouraged the author of this paper to carry out further surface geological studies in the Crimean Highlands. In this respect the excellent and readily accessible outcrops in the Salgir, Tonas and Sukhoy-Indol valleys were closely studied (Fig. 1). Based on the results of these studies, as well as on a review of publications and available subsurface data, a nappe model was developed for the Crimean Orogen (Popadyuk and Smirnov, 1991). In this paper we discuss the rationale which underlies this model and support our concepts with a series of structural cross-sections through the Crimean Highlands (Fig. 3).

TECTONO-STRATIGRAPHIC UNITS OF THE CRIMEAN HIGHLANDS

The distribution of the major tectono-stratigraphic units making up the Crimean Highlands, as well as the location of the transects discussed below, are given in Fig. 2. In essence five tectono-stratigraphic units are recognized. These are, in ascending order, the autochthonous unit which includes Early Cretaceous and Middle Jurassic strata, the allochthonous Taurian flysch group, the age of which was for a long time a matter of dispute, the allochthonous Late Jurassic Yayla unit and the largely post-tectonic Late Cretaceous to Cenozoic unit.which records evidence of Late Alpine deformation.

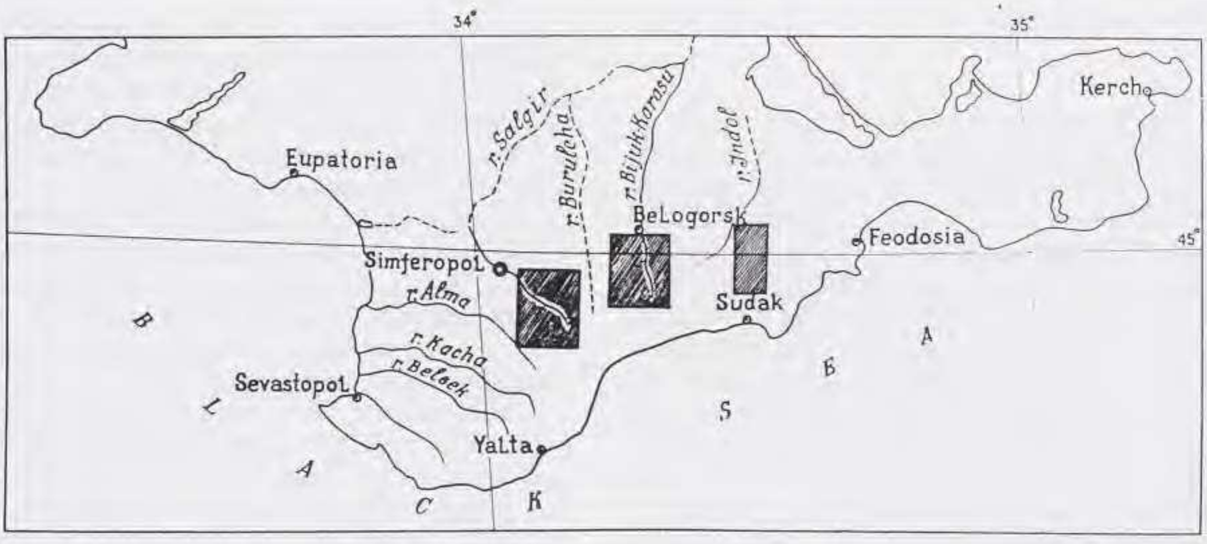


FIG. 1. Location map showing areas of detailed field work.

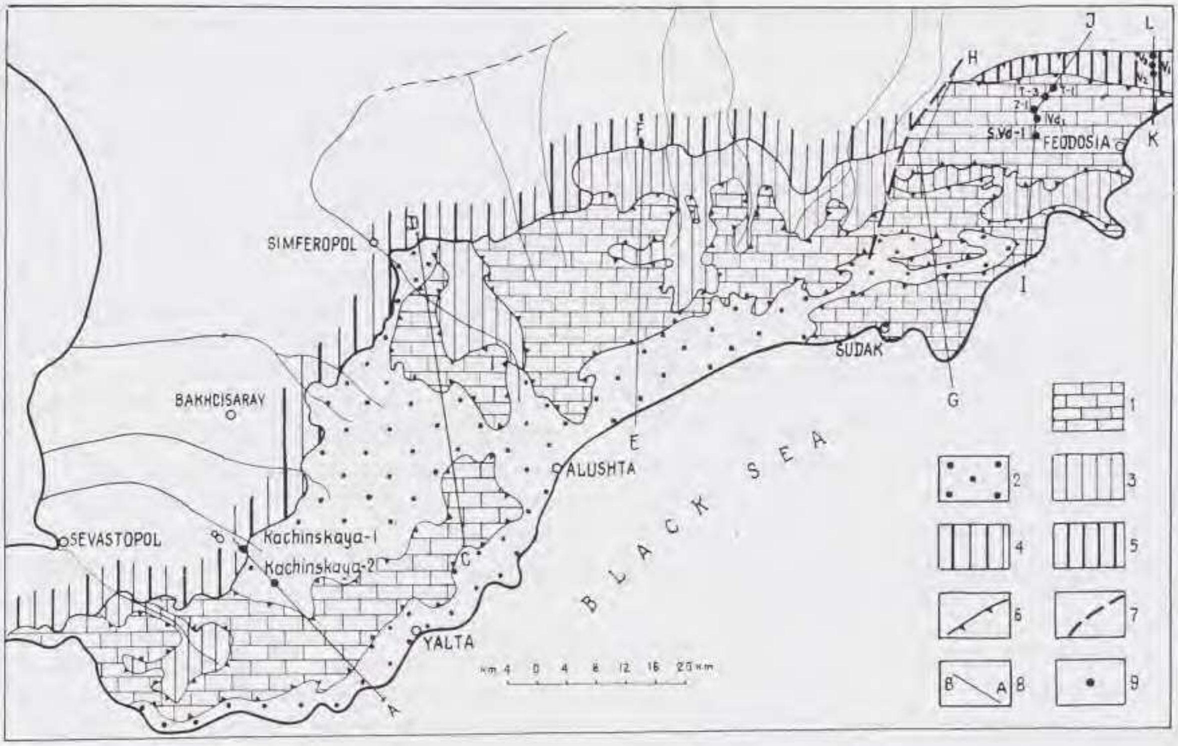


FIG. 2. Tectonic sketch-map of Crimean Orogen.
1: Yayla nappe; 2: Taurian nappe; 3: Early Cretaceous autochthonous series; 4: Late Cretaceous-Miocene neo-autochthonous series; 5: Vladislavovka nappe; 6: main thrust-faults; 7: postulated normal fault; 8: location of cross-sections given in Fig. 3; 9: well locations

Autochthonous Unit

The structurally lowest unit, which outcrops in the northern valleys of the Crimean Highlands, is referred to in our model as the autochthonous unit. In outcrops it consists of generally weakly deformed dark-gray, plastic Albian and Aptian clays, Barremian thin bedded flyschoïd sands, silts and shales, Hauterivian to Valanginian rhythmically bedded calcareous shales, silts and limestones and Berriasian calcareous shales and limestones. According to surface geological mapping and the results of boreholes, this sequence attains thicknesses of the order of 3.5 to 4.5 km and rests disconformably on a Middle Jurassic continental, coal-bearing series which exceeds 1 km in thickness. There is no information on the age, lithology and thickness of the pre-Mid-Jurassic autochthonous series and the basement on which it rest. Where control is available, the is no evidence for Late Jurassic carbonates in the autochthonous series, either due to their non-deposition or due to pre-Cretaceous erosion.

Taurian Flysch Unit

The Taurian flysch group, which was already recognized by Vogdt in 1902 as a special unit (Menner et al., 1947), overlays in outcrops Albian and older autochthonous strata. The Taurian flysch consists of intensely deformed dark-coloured, often black, rhythmically and thinly bedded shales, siliciclastic sands and silts. Within this sequence a coarse-clastic facies, referred to as the Eski-Odra formation, is locally recognized; it consists of sandstones, fine to coarse conglomerates and in some cases even giant limestone blocks which yield fossils of Carboniferous, Permian, Triassic and Lower Jurassic age. In some areas the Taurian flysch contains diabase bodies and tuffs.

The Taurian group has yielded numerous fossils such as Ammonites, Brachiopodes, Pelecipods, Gastropods, Beleminites, Crinoïdes, Foraminifera and plant imprints. As the majority of these fossils stem from carbonate olistoliths contained in the coarse-clastic Eski-Odra facies, they must be regarded as reworked. Their age ranges from Carboniferous to Permian, Middle and Late Triassic to Early and Middle Jurassic. The shales of the Taurian group contain only rare fossils. Conventionally the Taurian flysch group has been assigned a Late Triassic age. The Eski-Odra formation, regarded as forming part of the Taurian Group, was, however, thought to have an Early Jurassic age. By some the Taurian flysch was thought to range downwards into the Middle Triassic (Dagis and Shvanov, 1965) and the Eski-Odra formation to be as young as Middle Jurassic (Shalimov, 1960).

In some areas of the western Crimean Highlands, the shales of the Taurian group contain limestone blocks and olistostroms which yield early and middle Early Jurassic fossils Menner et al., 1947, see pp. 69-70). The occurrence of Early Jurassic faunistic remnants was also noted by Muratov (1960), Kazakova (1962) and Koronovsky and Mileyev (1974). A.S. Moiseev, one of the best experts in Crimean geology, remarked explicitly that the Late Triassic limestone blocks "represent themselves only blocks within the Taurian shales, similar to blocks of Permian rocks" (see Menner et al., 1947, pp. 58). A similar view was held by O.G. Tumanskaya who observed between the Bodrak and Salgir rivers that Permian, together with Liassic and Triassic limestones, formed a cliff consisting of blocks of different size which had settled into Triassic shales containing *Pseudomonotis caucasica* (see Menner et al., 1947, pp. 55). On the southern shore of the Crimea, near the village of Rybachiye, located to the west of Sudak, Taurian flysch equivalent strata yielded Bathonian fossils (Lychagin et al., 1956). From the Eski-Odra sequence, considered as having an Early Jurassic age, Middle Jurassic as well as Permian and Triassic fossils were retrieved (Muratov, 1960, 1969; Koronovsky and Mileyev, 1974). According to Shalimov (1960), the lower levels of the Eski-Odra formation (the so-called Salgir unit) contain Early Jurassic fossils whereas higher levels yield a mixture of Middle Jurassic, Late Triassic, Permian and Carboniferous fossils. However, the most interesting finds were made by Dekhtyareva et al. (1978) who describe from the Eski-Odra formation near Simferopol, apart from Triassic faunas, the occurrence of Ammonites straddling the Hauterivian-Barremian and the Middle-Late Aptian boundaries.

From the above it is concluded, that all Carboniferous to at least Jurassic fossils, which were retrieved from limestone or sandstone blocks as well as from sandstones and shales of the Taurian group, are reworked and therefore cannot be interpreted as giving the depositional age of the Taurian flysch. In this respect, even such delicate pelagic shells as *Pseudomonotis caucasica Witt* were reworked and are now found in a secondary position. For example, V. Bodylevsky described intensly deformed black shales containing blocks of calcareous sandstone and quartzite with purplish-red nodular siderite from which he retrieved, apart from *Pseudomionotis caucasica*, also *Halobia* and *Proarcestes* (Late Triassic). In some cases broken pieces of *Pseudomonotis* are found in friable shale intercalations, indicating, according to V. Bodylesky, that they were reworked in submarine flows or by wave action. More rarely *Pseudomonotis* occurs in nodular siderite where mainly *Halobia* is present (see Menner et al., 1947, pp. 65). In our opinion this does, however, not necessarely mean that these shells were reworked, as first assumed by V. Bodylevsky.

On the other hand, it is significant, that Late Jurassic carbonate fragments have never been reported from the Taurian flysch. Morover, it is interesting to note that the Hauterivian-Aptian Ammonites were also found in carbonate fragments, suggesting that they were reworked from the Yayla allochthon as carbonates of this age are not known from the Crimean autochthon.

At present no reliable in-situ fossils have been identified which could date the Taurian group. However, considering the youngest Ammonites, the Taurian flysch is provisionally assigned a Hauterivian to Aptian age.

In view of its intense deformation, the depositional thickness of the Taurian flysch cannot be determined. Moreover, no data are available on the direction of clastic transport. On the other hand, the occurrence of coarse mass flow deposits and of olistoliths and olistostroms within the Taurian flysch, composed of Carboniferous to Early Jurassic carbonates, indicates that it was deposited under tectonically increasingly unstable conditions in a deeper water basin of as yet unknown origin.

Yayla Unit

In outcrops, the Yayla unit overlays variably the Taurian flysch or different parts of the autochthonous unit. The Yayla unit is composed of Late Jurassic, partly reefal carbonates, which range in age from Kimmeridgian to Tithonian, and attain maximum thicknesses of 800-1000 m. Locally a basal conglomeratic unit is evident which usually is assigned to the Oxfordian-Early Kimmeridgian. In a few places the Yayla unit appears to include Neocomian carbonate flysch. The Yayla carbonates, which uphold the relief of the Crimean Highlands, are deformed to various degrees, though distinctly less intense that the Taurian flysch.

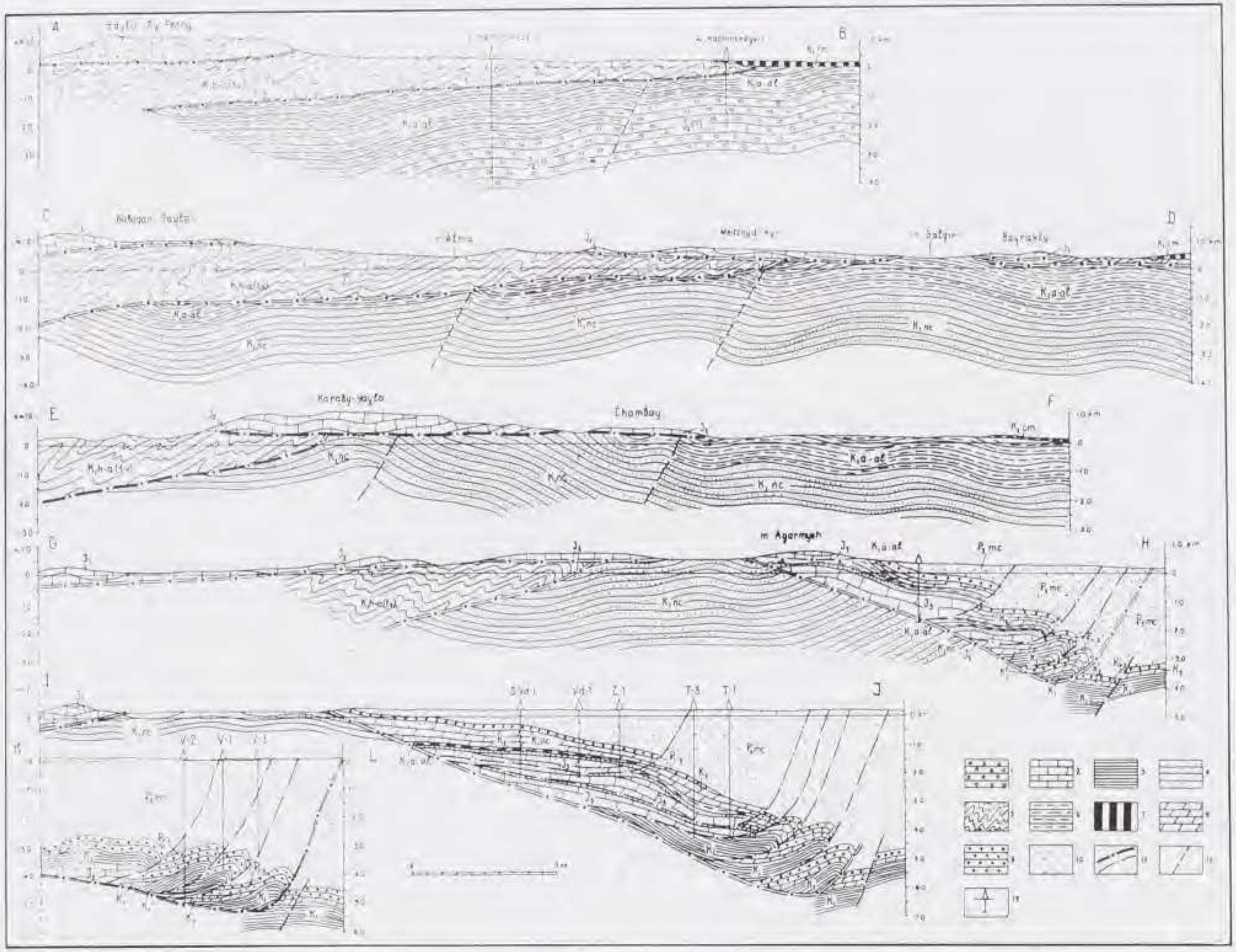
Late Cretaceous and Cenozoic Neo-autochthonous Unit

Along the northern margin of the Crimean Highlands, Late Cretaceous and Cenozoic strata unconformably overlay the mildly deformed autochthonous unit and the more intensely deformed Taurian and Yayla units. In the northeastern part of the Crimea, Cretaceous and Paleogne strata, together with Late Jurassic carbonates, are involved in the so-called Vladislavovka nappe, a structure that obviously records Late Alpine reactivation of the Yayla nappe (Fig. 2).

REGIONAL STRUCTURAL CROSS–SECTIONS

In Fig. 3 we present a set of regional structural cross-sections through the Crimean Highlands. These transects are based on detailed surface geological mapping and on an integration all available subsurface data. In the following results of our studies along the different transects will be discussed.

FIG. 3. Regional structural cross-sections through Crimean Orogen (for location see Fig. 2)
1: Middle Jurassic shales and silts containing rare coal intercalations; 2: Late Jurassic limestones and conglomerates of Yayla nappe; 3: Early Cretaceous shales, sandstones (Vladislavovka nappe); 4: Neocomian flysch-type shales and limestones (autochthonous unit); 5: Hauterivian to Aptian Taurian flysch series; 6: Albian-Aptian shales (autochthonous unit); 7: Cenomanian neo-autochthonous clastics and carbonates; 8: Late Cretaceous limestones, marls, shales and silts; 9: Paleocene shales, silts, marls and limestones; 10: Oligocene (Maïkop group); 11: thrust faults; 12: normal faults; 13: wells



Belbek Valley

The cross-section through the Belbek Valley area is built on surface geological data and the results of wells Kachinskaya-1 and -2 (Fig. 3, profile A-B). Kachinskaya-1 was spudded in gently north dipping Cenomanian limestones resting unconformably on the tightly folded Taurian flysch. Upon penetrating the base of the latter, the well entered into Aptian-Albian shales forming part of the autochthonous sequence. After drilling some 750 m of Early Cretaceous shales, a continental, coal-bearing Middle Jurassic sequence was encountered. The well was terminated before reaching the base of this Middle Jurassic series. Kachinskaya-2 was spudded in Taurian flysch and entered Albo-Aptian clays at a depth of 920 m; after penetrating 1854 m of little deformed Early Cretaceous and 1169 m of Middle Jurassic sediments, the well was abandoned.

Based on surface geological data and extrapolation of the well information it appears that the thickness of Taurian flysch increases southwards to about 1.5 km. The Yayla-Ay-Petry mountain is capped by some 1000 m thick Late Jurassic carbonates which rest directly on the Taurian flysch. To the southwest of the Belbek Valley, the Yayla carbonates cover the entire Taurian flysch and are in turn overstepped by Cenomanian deposits (Fig. 2).

The base of the Yayla and as well as of Taurian allochthon correspond to gently southward dipping thrust planes which are sealed by Cenomanian sediments along the northern margin of the Crimean Highlands. This indicates that these allochthons were emplaced during the Late Albian on a little deformed autochthonous sequence, consisting of Aptian-Albian shales which rest disconformably on a thick Middle Jurassic sequence.

Salgir Valley

In the topographically lowest part of the Salgir Valley, dark-grey to black, plastic and weakly deformed Albian clays outcrop in several tributaries of the Salgir river (Fig. 3, profile C-D). On the eastern slopes of this valley, massive Late Jurassic limestones, forming the Yayla plateau, rest directly on Albian clays. The contact between the Jurassic carbonates and the Albian clays is concealed by scree slopes and giant blocks which have tumbled down from the edge of Yayla plateau. However, as this contact is clearly marked by a system of springs, it can be readily mapped. The contact between the Albian clays and the Late Jurassic limestones is interpreted as a sub-horizontal thrust fault.

Along the southern and western slopes of the Salgir Valley, the Early Cretaceous sequence extends stratigraphically downwards into the Aptian and consists of dark-grey clays containing silty and fine-grained sandstone intercalations. In one of the tributaries of the Salgir river the Aptian sequence is directly overlain by the Taurian flysch; the latter consists of strongly deformed, rhythmically bedded shales, silts and quartzitic sandstones. However, the contact between the Aptian clays and the Taurian flysch is poorly exposed. Similarly, the contact between the Taurian flysch and the overlaying Jurassic carbonates is essentially concealed by scree. In this area the Jurassic sequence consists of massively bedded Kimmeridgian conglomerates with a carbonate matrix; these grade upwards into the massif Tithonian carbonates. The components of the Kimmeridgian conglomerate are made up of quartz, sandstones, metamorphic shales and limestones.

Topographically speaking, the Late Jurassic conglomerates and limestones form the uppermost unit. Further south, this unit rests on highly deformed Taurian flysch and further to the north directly on weakly deformed Aptian and Albian clays. Where present, the Taurian flysch overlays Early Cretaceous clays and thus forms the middle unit. The Albian-Aptian clays form part of the basal autochthonous unit. Both the Taurian flysch and the Late Jurassic Yayla unit are allochthonous and were apparently thrusted northwards over the autochthonous Aptian-Albian clays. Across the Salgir Valley, erosion has cut through the Yayla and Taurian thrust sheets into the underlying autochthonous unit; as such the Salgir Valley represents a tectonic half-window. Surface geological evidence indicates the the autochthonous series extend a minimum of 20 km under the combined Yayla and Taurian thrust sheets. The Bayrakly and

Medshyd-Kyr hills are upheld by klippen of the Yayla thrust sheet which are partly underlain by the Taurian thrust sheet. Although the southern part of the cross-section C-D is based on limited subsurface data and is therefore schematic, it suggests that the Yayla thrust-sheet was transported northwards over a distance of at least 35 km along a sub-horizontal thrust-fault, separating it from the Taurian thrust-sheet, which in turn traveled a similar distance over the autochthonous foreland. Both the Yayla and the Taurian thrust-sheets can be regarded as major north-verging nappes.

Tonas Valley

The Tonas Valley is located in the head-waters of the Biyuk-Karasu river (Fig. 1). South of the city of Belogorsk, weakly deformed Aptian-Albian clays occupy the valley floor (Fig. 3, profile E-F). 5.5 km south of Belogorsk, outcrops of thinly bedded flyschoid dark-gray shales, silts and sandstones of Barremian age are observed. Further upstream, progressively older strata are exposed; a more shaly section is followed by monoclinally north dipping rhythmically bedded calcareous shales, siltstones and limestones of Valanginian-Hauterivian age and Berriasian calacreous shales and limestones. The lower parts of this sequence are characterized by 10-15 m thick cycles, each of which commences with a limestone conglomerate which grades upwards into limestones and calcareous shale. The basal parts of the Cretaceous are characterized by 1-2 m thick limestone beds. Along the road leading up to the Alikot-Bogas pass, more strongly deformed calcareous shaly flysch, containing sand intercalations, is observed; these sediments are interpreted as equivalents of the Barremian.strata seen south of Belogorsk.

In the Tonas Valley a 3.5-4.5 km thick sequence of Albian to Berriasian flyschoid autochthonous series can be observed. However, its base has not been seen and it is unknown what underlies it.

Four kilometres to the south of Belogorsk, the hills flanking the Tonas Valley are capped by massively bedded Late Jurassic limestones and alternating limestones and shales of Tithonian-Berriasian age. Since these carbonates rest on Albian shales, they are attributed to the Yayla nappe. Apparently this nappe rests in the Tonas Valley directly on various levels of the autochthonous sequence. The Taurian nappe is only recognized under the southern parts of the Karaby-Yayla hills from where it continues to the Black Sea coast. The Karaby-Yayla hills form part of a major Yayla nappe klippe.(Fig. 2). Similar to the Salgir Valley, the Tonas Valley is interpreted as a tectonic half window which developed in response to erosion of the allochthonous units. Surface geological criteria indicate for the Tonas Valley area a minimum of 15 km northward transport of the Yayla nappe over the autochthonous foreland.

Sukhov-Indol Valley

On the eastern slopes of the Idol Valley, Mount Agarmysh represents the northernmost remnant of the Yayla nappe (Fig. 3, profile G-H; Fig. 4). Late Jurassic limestones, which uphold this mountain, rest directly and in thrust-contact on Albian-Aptian autochthonous clays. As nowhere else, it is here possible to closely observe the internal structure of the Yayla nappe. Mount Agarmysh provides in a cliff-face of over 400 m and in a quarry on its southern flank excellent exposures. These show that the upper parts of Mount Agarmysh are composed of gently folded, massif Tithonian limestones (Fig. 4b). Along the southern flank of Mount Agarmysh, fine-grained Neocomian siliciclastic flysch and conglomeratic limestones, intercalated with calcareous shales and reminiscent of the Berriasian series of Tonas Valley, are exposed. In the Agarmysh quarry, an olistostrom is recognized which is composed of large Late Jurassic limestone and Neocomian siliciclastic flysch blocks; these are encased in a shaly matrix of unknown age (Fig. 4a). The thrust contact between the Tithonian to Neocomian sediments of the Yayla nappe and the underlaying Apto-Albian shales is sub-horizontal and appears to be paralleled by a subsidiary thrust fault located some 110 m above the sole-thrust of the Yayla nappe.

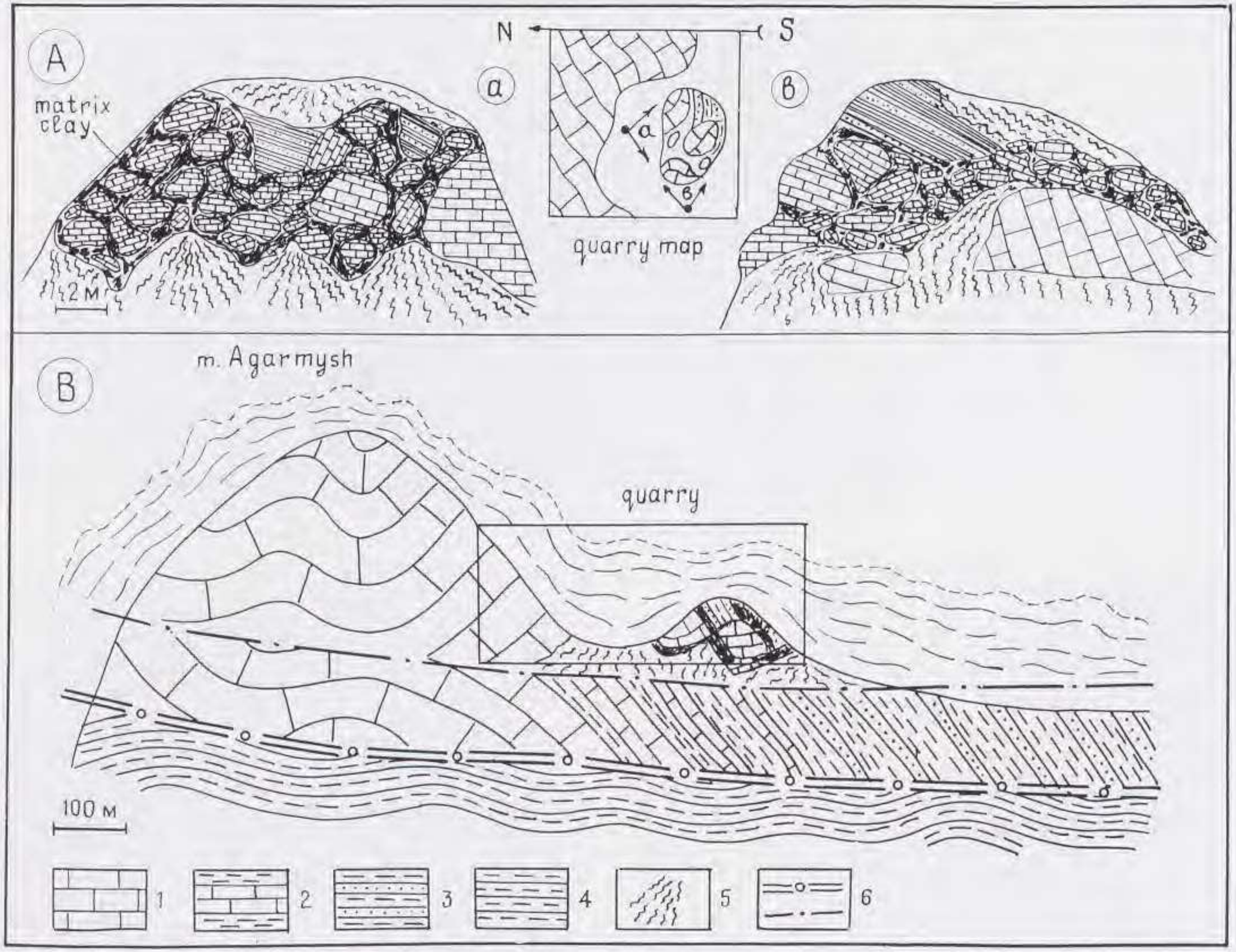


FIG. 4. Geological cross-section through Mount Agarmysh
A: north and west wall of Agarmysh quarry; B: Agarmysh Mountain showing location of quarry; 1: Massif Tithonian limestone; 2: Tithonian-Berriasian flysch-type shales and limestones; 3: Neocomian sandy flysch; 4: Aptian-Albian dark-gray, non-calcareous shales; 5: talus; 6: sole-thrust of Yayla nappe and intra-Yayla thrust fault

The northern part of section G-H is based on sub-surface data which indicated that the sole-thrust of the Yayla nappe plunges northwards and that it was apparently active during Cenozoic times as evident be the imbrication of Late Cretaceous and Paleogene sediments. A similar pattern is shown in profiles I-J and K-L which cross the Vladislavovka nappe and are closely controlled by boreholes. Several wells drilled in this area penetrated the basal sole-thrust and bottomed below Late Jurassic carbonates in little deformed Neocomian sediments (Voloshyna, 1977).

The southern parts of profile G-H illustrate that the Taurian nappe appears beneath the Yayla nappe to the south of an erosional window in which Neocomian flyschoid series of the autochthon are exposed. On the basis of this profile, a horizontal northward transport of the Yayla nappe, amounting to some 35 km, can be postulated.

DISCUSSION

Based on the results of our research, we propose that the configuration of the Crimean orogen is dominated by the Yayla nappe, which involves mainly Late Jurassic carbonates, and by the Taurian nappe, which is composed of Early Cretaceous flysch. Palaeontological, surface geological and sub-surface data clearly demonstrate that emplacement of both nappes resulted in the superposition of older over younger strata.

The Yayla and the subjacent Taurian nappe were thrusted northward over an autochthonous series which includes Middle Albian.and older strata. At their northern margin, both the Yayla and the Taurian nappes are overstepped by undeformed Cenomanian and younger sediments which also seal their basal thrust-faults. Within the basal parts of these post-tectonic transgressive sediments, reworked Hauterivian, Barremian, Aptian and Albian faunas were recognized, together with limestone conglomerates and fragments of Taurian flysch; these basal beds grade upwards into undisputable Cenomanian limestones as seen, for instance, in the Alma and Bodrak valleys. At some stage the question of the lower age limit of the neo-autochthonous series gave rise to considerable controversy. However, in view of a definitely Mid-Albian upper age limit of the autochthonous series, we conclude that the final emplacement of the Yayla and Taurian nappes occurred during the Late Albian.

Therefore, the main deformation phase of the Crimean Highlands can be safely dated as Late Albian. As such it coincides with the Austrian phase of the Alpine orogenic cycle and not, as previously postulated, with the Early Cimmerian phase (Muratov, 1960, 1969; Muratov and Tseisler, 1982). Similarly, a Mid-Cretaceous compressional phase governed the development of the Dobrogean orogen for which a previously postulated Early-Cimmerian compressional deformation must be rejected on the basis of newer litho- and biostratigraphic data (Gradinaru, 1984).

For the northeastern part of the Crimean Highlands, subsurface data clearly demonstrate an Eocene and younger reactivation of the Yayla nappe; this reactivated zone is referred to as the Vladislavovka nappe. The extent to which the remainder of the Crimean Highlands were affected by these Cenozoic deformations is uncertain. However, the erosional edge of the Cenomanian and younger post-Austrian neo-autochthonous series suggest at best a regional upwarping of the entire area and minor faulting. Such upwarping of the entire Crimean Highland probably entailed a modification of the geometry of the Yayla and Taurian nappe sole-thrusts.

The Yayla nappe, which at present consists of a system of klippes, is presumably rooted off-shore in the Black Sea. Remnants of this major nappe, which attains thickness of some 800 to 1000 m, indicate that is was transported in a northwesterly direction over a distance of at least 40 km; its lateral extent is about 140 km. Although the internal structuration of the Yayla nappe is very complex and is far from being resolved, its sole-thrust is sub-horizontal and plunges only northwards in the domain of the Vladislavovka nappe.

In a strike direction the Taurian nappe extends over a distance of 140 to 150 km. In a dip direction its distribution is very variable; in the Yalta-Bakhcisaray sector it has a length of at least 40 km whereas in the Alushta-Sudak sector and to the southwest of Yalta it does not exceed 10-15 km (Figs. 2 and 3). The thickness of this complexly deformed nappe is difficult to estimate. Although a minimum thickness of 1 km is ascertained by well data, it is likely that the thickness of this nappe increases to 2 or more km to the south in non-eroded areas.

CONCLUSIONS

The Crimean Orogen consists of the Taurian and Yayla nappes which were thrusted northwards across the autochthon over a distance of at least 40 km during the Mid-Cretaceous Austrian phase of the Alpine orogeny. There is no evidence for an Early-Cimmerian compressional deformation of the Crimean Highlands. Paleogene reactivation of the Crimean orogen appears to be restricted to its northeastern parts, though contemporaneous broad arching of the entire Crimean Highlands cannot be excluded.

Although our understanding of the architecture and the timing of deformation of the Crimean orogen has greatly advanced, much remains to be done in order to understand the evolution of the basin out of which this thrust belt evolved. Some of the outstanding questions are: Did emplacement of the Yayla and Taurian nappes involve in-sequence or out-of-sequence thrust propagation? From where did the Yayla carbonate platform originate and what processes governed the subsidence an closure of the Taurian flysch trough? What is the derivation of the Carboniferous, Permian, Triassic and Early Jurassic olistoliths and olistostroms contained in the Taurian flysch? What is the geotectonic setting of volcanic activity associated with the Taurian flysch? Can indeed a relationship be established between the evolution of the Dobrogea and the Crimean basin?

At this stage we are still far away from attempting a palinspastic and historical restoration of the Crimean Orogen, which in all probability would contribute materially to the understanding of the evolution of Tethys and its flanking platforms.

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